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Selective growth of InGaAs on nanoscale InP islands

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The formation of an InGaAs quantum well on nanoscale InP islands by selective growth using metalorganic vapor phase epitaxy is demonstrated. The structures show intense low-temperature photoluminescence at 1.35 eV. The blueshift of the emission peak by increasing the excitation intensity suggests that the carriers are three-dimensionally confined. The insertion of quantum well into the islands allows a better control of the properties of structures fabricated by the self-organizing growth, a novel technique to realize nanoscale structures without using any lithographical process steps.

Utilization of lattice mismatch induced three-dimensional growth is a novel technique to produce structures containing nanoscale islands, providing means to fabricate quantum box structures with a relative ease. Examples of this technique are the formation of InAs or InGaAs dots on GaAs by molecular beam epitaxy (MBE),[1,2] the growth of InAs nanoclusters on InP by metalorganic vapor phase epitaxy (MOVPE),[3] or the growth of nanoscale InP islands on GaAs by hydride vapor phase epitaxy (VPE).[4] In this letter, the selective growth of InGaAs quantum wells on such nanoscale InP islands is reported. Introducing a quantum well in the nanoscale islands brings more freedom into the designing the structures due to the possibility of controlling the band gap of the well, and of controlling the strain caused by this extra layer.

The samples were grown by atmospheric pressure MOVPE from trimethylgallium (TMGa), trimethylindium (TMIn), tertiarybutylarsine (TBAs), and tertiarybutylphosphine (TBP). Various structures for the characterization by atomic force microscope (AFM), by scanning electron microscope (SEM), or by photoluminescence (PL) measurements were fabricated. The structures were grown on semi-insulating (100)GaAs 0°, 2°, or 4°-off wafers. The substrates were heated up to 700 °C prior to the growth of a 200-nm-thick GaAs buffer at 650 °C. The InP islands were deposited at 650 °C using TMIn flows of 1.3–3.9 μmol/min and a V/III ratio of 20–50. The deposition time was 4–15 s. The deposition of InP on GaAs results in the formation of small InP islands on the surface.[4] The island density shows slight dependence on the substrate off-angle. A density of 2×10^9 cm^{-2}, 3×10^9 cm^{-2}, and 3.5×10^9 cm^{-2} of the islands on substrates with off-angles of 0°, 2°, and 4°, respectively, was obtained. This dependence on off-angle is much weaker in MOVPE than in hydride VPE.[5] An AFM image of InP islands on a 2°-off (100)GaAs substrate is shown in Fig. 1(a). The average width of the islands is less than 100 nm and the average height is about 20 nm. The areal density of the islands is 3×10^9 cm^{-2}. On this surface a nominally 10-nm-thick layer of InGaAs, lattice matched to InP, was deposited. An AFM image of the resulting surface is shown in Fig. 1(b). The areal density of the islands is the same as in Fig. 1(a). The size distribution of the islands is broader and the average height of the islands is increased to about 37 nm. The images in Figs. 1(a) and 1(b) were not measured with the same tip in AFM, thus the lateral size of islands in Figs. 1(a) and 1(b) are not comparable. The increase in the total volume of the islands corresponds roughly to the total amount of the deposited InGaAs. This suggests that InGaAs grows exclusively on the InP islands.

To verify this, a sample with larger InP islands and a thicker layer, nominally 25 nm, of InGaAs was grown for inspection by scanning electron microscopy. The longer deposition time results in a broader size distribution of islands, ranging from sub-100-nm islands to islands more than 100 nm high and 200 nm wide. The islands were grown on a thin, 2-nm-thick GaAs layer, grown on top of a 100-nm-thick InGaP layer. After the deposition of InGaAs, the structure was covered by a 350-nm-thick layer of InP. Prior to the SEM inspection, the samples were cleaved and stain etched in HNO_3:H_2O (1:1) solution to reveal the location of arsenides. A sideview SEM micrograph of a stain etched structure is shown in Fig. 2. Clearly, the InGaAs grows exclusively on the InP islands and no growth of arsenides between the islands is observed.

The photoluminescence spectra were measured using normal lock-in techniques with a Ge detector cooled to 77 K. For excitation, the 488-nm line of an Ar^+-ion laser was used. The laser beam was focused to a spot with a diameter of about 0.2 mm. A sample with similar InP islands and an InGaAs layer like in Fig. 1, buried with a 350-nm-thick InP layer, shows at 12-K broad emission ranging from 0.78 to 0.95 eV. The peak originates most likely from the relatively thick InGaAs layer. The peak position and the width suggest that the islands and the InGaAs film are at least partially relaxed. The size distribution may also be one reason for the broad peak.

To improve the carrier confinement into the region where the islands are located, 100-nm-thick InGaP barriers were added below and on top of the structure. A 2-nm-thick GaAs layer was grown on the lower InGaP layer prior to the

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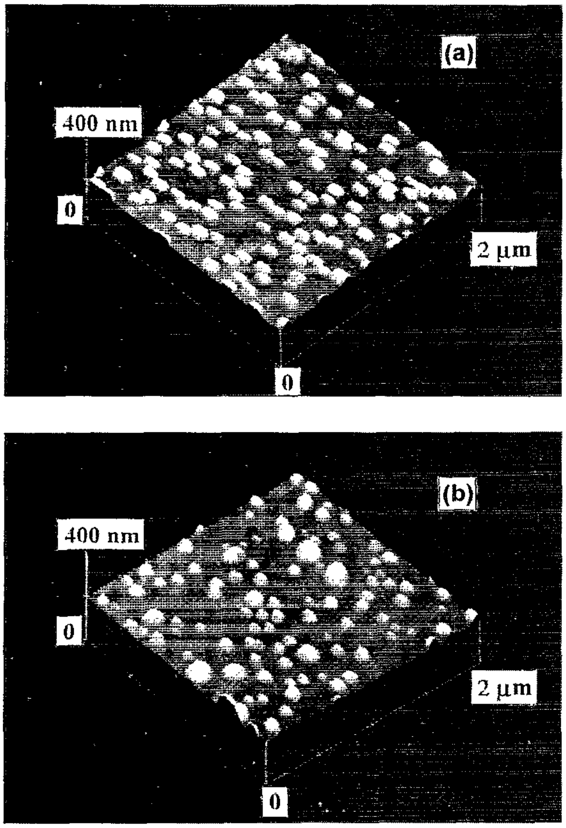

FIG. 1. An AFM image of InP islands on (100)GaAs substrate (a). The areal density of islands is 3×10^9 cm^{-2}. The structure after the deposition of nominally 10-nm InGaAs is shown in (b). The images in (a) and (b) were recorded using different tip and the lateral size and shape of the islands are not comparable.

deposition of InP and InGaAs. A thin InP layer was deposited after the deposition of the InGaAs. AFM measurements from an unburied structure gave an average height of about 10 nm and an average width of about 50 nm for the InP islands. The areal density of the islands was 8×10^9 cm^{-2}. PL spectra at 12 K at various excitation intensities is shown in Fig. 3. At

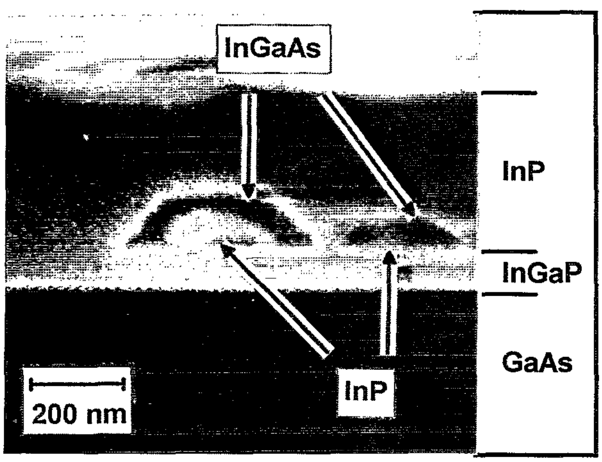

FIG. 2. A cross-sectional SEM micrograph of a cleaved and stain etched structure showing the selective growth of InGaAs on the InP islands.

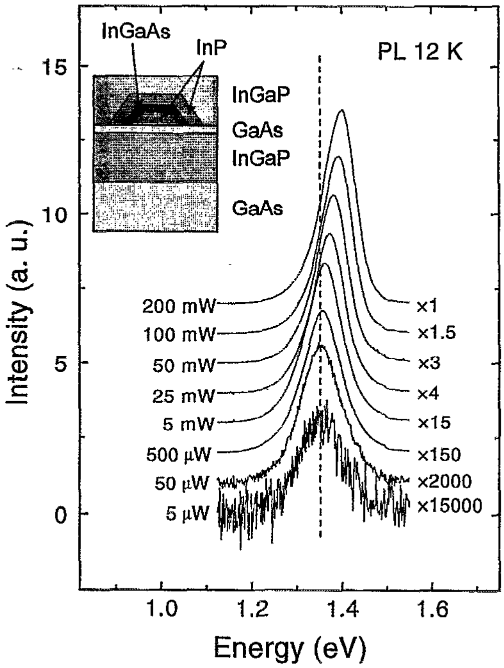

FIG. 3. 12-K photoluminescence spectra at various excitation levels from a structure in which the InP islands with the InGaAs wells are cladded by InGaP barriers. The structure is schematically shown in the inset. The emission shifts to higher energy at higher excitation levels, suggesting that the carriers are three-dimensionally confined.

low excitation the peak is at 1.35 eV. By increasing the excitation, the emission shifts to higher energy. At the excitation power of 200 mW, the peak is shifted by 50 meV. A similar sample with twice the amount of InGaAs emits at 1.30 eV at low excitation and shows a blueshift of 40 meV at higher excitation levels. The emission intensity from samples buried with InGaP is about 100 times higher than from the sample buried by InP. At room temperature the emission intensity drops to one-tenth, and the peak is at 1.30 eV from the sample with the thinner InGaAs layer and at 1.17 eV from the sample with the thicker layer of InGaAs. The results show that the optical quality of the structures is very good.

The shift of the InGaAs related emission from the bulk value of 0.8 to 1.3 eV is, in addition to the quantum confinement, probably caused by strain. When the islands are small enough, the structure is completely strained and this compressive strain increases the band gap. PL emission from small InGaAs islands at around 1.2 eV has been reported.[2] Intermixing of the materials could also shift the emission peak. The SEM micrograph from a structure with thick layers suggests that no intermixing occurs, but the situation may be different when the islands become very small. The amounts of the group III elements between the InGaP barriers allow, in the case of total intermixing, a formation of a composition with equal amounts of Ga and In. The lattice matching condition would require the formation of InGaP. This is controversial to the PL results, and at least a complete mixing can be ruled out.

The strong blueshift with increasing excitation power suggests that the carriers are three-dimensionally confined.[6]

If the structure was effectively a quantum well, a redshift due to band-gap renormalization should occur.[7]

The mechanism leading to the selectivity is not clear at present. Large islands may be partially relaxed, and in the case of small, unrelaxed islands, the strain is accommodated by both the islands and the substrate under the islands.[8,9] This means that the islands have a larger lattice constant than the surrounding substrate surface. Thus one possible reason for the selective growth is that InGaAs grows preferably on islands due to smaller lattice mismatch.

In summary, selective growth of InGaAs on nanoscale InP islands is demonstrated. The structures were grown by MOVPE in a single run on planar substrates without lithographical process steps. The structures have good optical quality showing intense photoluminescence, making this self-organizing growth a potential candidate for a fabrication technique of nanoscale heterostructures.

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